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WATER QUALITY IN A CENTRAL OKLAHOMA STREAM AS INFLUENCED BY FISH HATCHERY EFFLUENT

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WATER QUALITY IN A CENTRAL OKLAHOMA STREAM AS INFLUENCED BY FISH HATCHERY EFFLUENT

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ABSTRACT

Runoff from a rangeland watershed and effluent from the Tishomingo National Fish Hatchery were monitored in Pennington Creek, Okla., from May 1971 through April 1972 for several forms of nitrogen, total and soluble phosphorus, calcium, magnesium, biological oxygen demand, dissolved oxygen, coliform populations, pH, and temperature. Measurements, made monthly and bihourly during one 24-hour period, indicated no degradation of stream water quality occurred due to rangeland or hatchery discharge. The rangeland runoff appeared to contain less total nitrogen and phosphorus than received in rainwater. On occasion, hatchery effluent did cause a change in nitrogen forms in the stream, but without altering the total concentration. During the feeding season, the hatchery effluent increased total phosphorus in the stream.

INTRODUCTION

In 1971, the Division of Fish Hatcheries of the Bureau of Sports Fisheries and Wildlife, U.S. Department of the Interior, requested several National Fish Hatcheries to supply data on their pollution potential. This request and a need by the U.S. Department of Agriculture (USDA) for information about nutrient discharge from various types of agricultural watersheds resulted in a study in which several chemical and physical variables of Pennington Creek, Okla., were measured during a period extending from May 1, 1971, through April 30, 1972.

The watershed discharge basin above the Tishomingo National Fish Hatchery, Okla., was suitable in several ways for obtaining information on the influence of agricultural activity on the quality of drainage waters. Among its characteristics were an absence of urban population or industrial influences, moderate annual precipitation, and extensive agricultural utilization involving little land tillage. Simultaneously, the Tishomingo National Fish Hatchery utilized a sufficient portion of the watershed discharge to enable detection of the influence of hatchery activity on water quality without great difficulty. This report summarizes the observations on water quality obtained in the study.

MATERIALS AND METHODS

Sampling-Site Descriptions

Pennington Creek, located in the Washita River basin near Lake Texoma in central Oklahoma, originates in northern Johnston and southern Pontotoc Counties approximately 16 to 24 km (10 to 15 mi) northwest of the Tishomingo National Fish Hatchery. Pennington Creek flows through middle and lower Paleozoic sedimentary formations, with the exception of a small area of older Precambrian sediments near the mouth of the stream (*5, 11*).[2] The watershed vegetation is composed primarily of mixed hardwood forest along the streambanks and native prairie grasses on the upland slopes. Soils in the area are paleustalfs and argiudolls, with some hapludolls, ar-

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[2] Italic numbers in parentheses refer to items in "Literature Cited" at the end of this publication.

giudolls, and argiustolls bordering the upper reaches of the stream. The Pennington Creek drainage basin has a low population density. The basin above the hatchery encompasses an area of approximately 168 km² (65 mi²) and has a gently rolling topography.

Estimation of land utilization in the drainage basin above the hatchery was made with the aid of aerial photos. Grazing, the predominant land use, occupies 75% to 80% of the upper Pennington Creek drainage basin. About 1% of the land is utilized for hay production, and another 1% is tilled for crops. The remaining area, 20% to 25%, is forested, and much of the forested area is also grazed.

The Tishomingo National Fish Hatchery is located 11.3 km (7 mi) northwest of Tishomingo, Okla. The hatchery has 15.3 ha (37.5 acres) of ponds for which it utilizes water from and discharges water into Pennington Creek. A schematic of the Tishomingo National Fish Hatchery and Pennington Creek sampling sites is given in figure 1. The six stations selected for sampling were (1) on an upstream supply reservoir from which water is diverted via a canal to the hatchery; (2) on Pennington Creek adjacent to the hatchery grounds below the reservoir and above the effluent canal-creek junction (fig. 2); (3) on the major effluent canal which carried 75% of

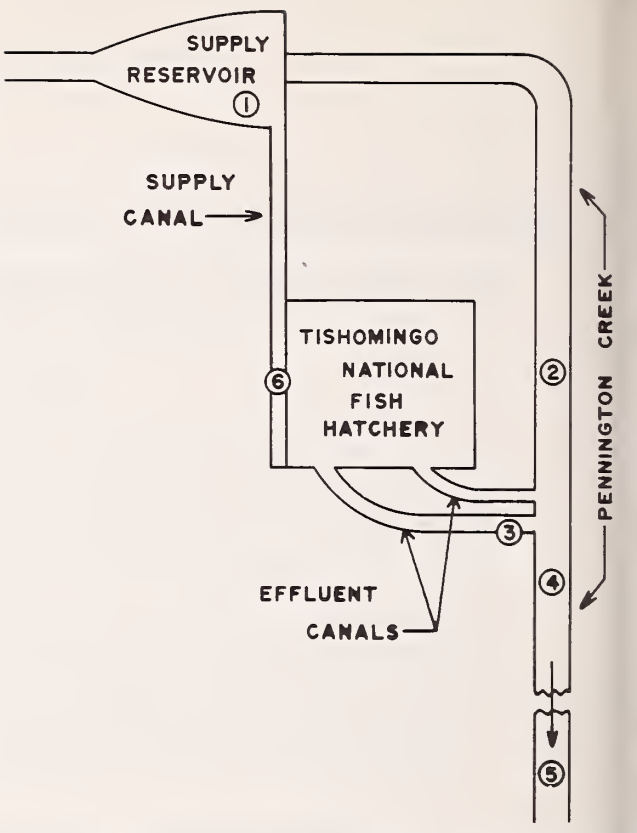

FIGURE 1.—Schematic of Tishomingo National Fish Hatchery and Pennington Creek. Numbers indicate sampling stations. Flow rates were measured in Pennington Creek at station 2 and in the hatchery effluent canals.

FIGURE 2.—Sampling station 2, Pennington Creek. Grab samples were obtained directly below the bridge. This site also served as the stream-gaging station.

the hatchery effluent (fig. 3); (4) on Pennington Creek, 150 m (500 ft) below the effluent canal-creek junction; (5) 8 km (5 mi) below the junction; and (6) at the terminal end of the hatchery supply canal. At stations 2, 3, 4, and 5, the waterflow was moderate to swift, and at stations 1 and 6 the flow was slow and placid. The supply reservoir had a depth of about 1.5 m (5 ft) and a surface area of about 837 m^2 (9,000 ft^2). A few bottom-rooted aquatic plants were observed around the shallower edges of the reservoir in 1972. The supply canal contained a copious growth of bottom-rooted vegetation [*Nelumbo lutea* (Willd.) and *Nuphar advena* (Ait. f.) predominate] having extensive aerial foliation which obscured large portions of the canal surface.

Sampling

Water samples were obtained at approximate 1-month intervals from May 1971 through April 1972. Samples of approximately 3.8 liters (1 gal) were collected at each sampling station and placed in polyethylene containers. Temperature, dissolved oxygen content, and pH measurements were made in situ daily.

One 24-hour survey of N, Ca, Mg, pH, temperature, dissolved oxygen content, total and suspended solids content, and biochemical oxygen demand (BOD) was conducted from August 31 to September 1, 1971. Twelve samples were collected at alternate hours beginning at 10 p.m.

All samples were immediately refrigerated, then packed in ice and shipped to Agricultural Research Service's Water Quality Management Laboratory, Durant, Okla. After arrival at the laboratory, all samples were stored at 4° C in conventional refrigerators. Samples were shaken immediately prior to subsampling or filtration or both. Millipore filters having 0.45 μm pores were used during filtration with vacuum suction.

Chemical Analyses

Chemical analyses for total Kjeldahl N, nitrate N, nitrite N, ammonia N, alkalinity, Ca, Mg, total solids, suspended solids, and settleable solids were made by standard methods (*12*). Total Kjeldahl and ammonia N concentrations were determined with a micro-Kjeldahl distillation apparatus and Nessler's reagent. Nitrate N was determined with brucine sulfanilic acid, and nitrite N, with buffered sulfanilamide reagent. Alkalinity was determined by titration with 0.05 *N* HCl. Calcium and magnesium were determined by atomic absorption spectrophotometry.

Total P content was determined by the perchloric acid digestion method described by Golterman and Clymo (*4*). After digestion, color was developed with ammonium molybdate, and the complex was extracted with isobutanol. Total

FIGURE 3.—Sampling station 3, the hatchery effluent and Pennington Creek junction.

water-soluble P (soluble inorganic and organic phosphates and polyphosphates) was determined on filtered samples after digestion with perchloric acid in the same manner as for total P. Water-soluble orthophosphate P was determined on filtered samples without digestion by the isobutanol extraction procedure.

Laboratory methods for determination of ammonia N, nitrate N, Kjeldahl N, alkalinity, Ca, Mg, and P were checked against standard samples from the Cincinnati laboratory of the U.S. Environmental Protection Agency. All results were within ±10% of the quoted standard. With replicate analyses, the following standard deviations were found for each analysis: ammonia N, 0.04 mg/l; nitrite N, 0.001 mg/l; nitrate N, 0.03 mg/l; Kjeldahl N, 0.06 mg/l; and alkalinity, 4 mg/l.

Total and fecal coliform counts and BOD measurements were determined by the Kerr Water Pollution Laboratory, Ada, Okla., with procedures described by the American Public Health Association (*1*).

Precipitation and Flow Measurements

Precipitation records were obtained for the three weather stations nearest the upper Pennington Creek watershed (*6, 7*). A Thiessen weighted average of precipitation received (*3*) was determined for the watershed area.

The volume of hatchery discharge was determined with Parshall flumes in both hatchery effluent canals. Mean monthly discharge measurements were totaled to obtain annual discharge.

Pennington Creek discharge measurements were made at station 2, a channel-control site with a rock bottom. Flow rate was estimated with the aid of a staff gage and calibration charts prepared by the U.S. Geological Survey, and was recorded on all regular working days.

RESULTS AND DISCUSSION

Monthly and Annual Mean Flows

The watershed discharge monitored at station 2 contained approximately 80% of the nutrients discharged from the upper Pennington Creek drainage basin (about 20% was diverted through the hatchery). The flow rates recorded at station 2 and those of the combined hatchery effluent canals are shown in figure 4. The estimated annual mean flow at station 2 was 7.4 hectoliters per second (hl/s), or 26 ft^3/s. The hatchery effluent flow was quite uniform, with an annual mean flow of 1.9 hl/s (6.8 ft^3/s). The combined station 2 and hatchery-effluent mean-flow estimate was 9.3 hl/s (32.8 ft^3/s), which is comparable to the U.S. Geological Survey's independently estimated mean flow for Pennington Creek of 9.9 hl/s (35 ft^3/s) for the study period; the estimated mean annual flows of Pennington Creek were much lower than the long-term average annual flow, recorded at station 2, of approximately 14 hl/s (50 ft^3/s).[3] The total discharge through station 2 and from the hatchery supply canals was approximately 2,930 hectare-meters (ha-m), or 23,800 acre-ft. Visual observations confirmed the somewhat abrupt decline in flow from 7.4 to 0.57 hl/s (26 to 2 ft^3/s) at the end of July.

The data on stream temperatures and pH at station 2 are illustrated in figure 5. The temperature of the runoff water ranged from about 5° C in the winter to greater than 30° C in midsummer. The pH at station 2 remained nearly constant at 8.0 with the exception of the months of July and August when a pronounced drop to values of less than 7.0 was observed.

Total estimated precipitation received in the upper Pennington Creek watershed during the study, about 98.6 cm (38.8 in), equaled the long-term annual average received in this region. The fact that the runoff from the watershed was much lower than the long-term average can be partly attributed to a more uniform rainfall distribution than is usual in the area. Rain gage reports from the three nearest recording stations are shown in figure 6. These gages were located outside the boundaries of the watershed as follows: Sulphur station is WNW of the watershed and received 89.7 cm of rainfall (35.4 in); Pontotoc station is ENE of the watershed and received 104 cm (40.7 in); and Tishomingo station is SSE of the watershed and received 95.2 cm (37.5 in). The three rainfall distribution patterns were quite similar. The total water yield

[3] Irwin, J. H. 1973. Personal postal communication with the authors. Address: U.S. Department of the Interior, Geological Survey, Water Resources Division, Room 4301, 200 NW 4th St., Oklahoma City, Okla. 73102.

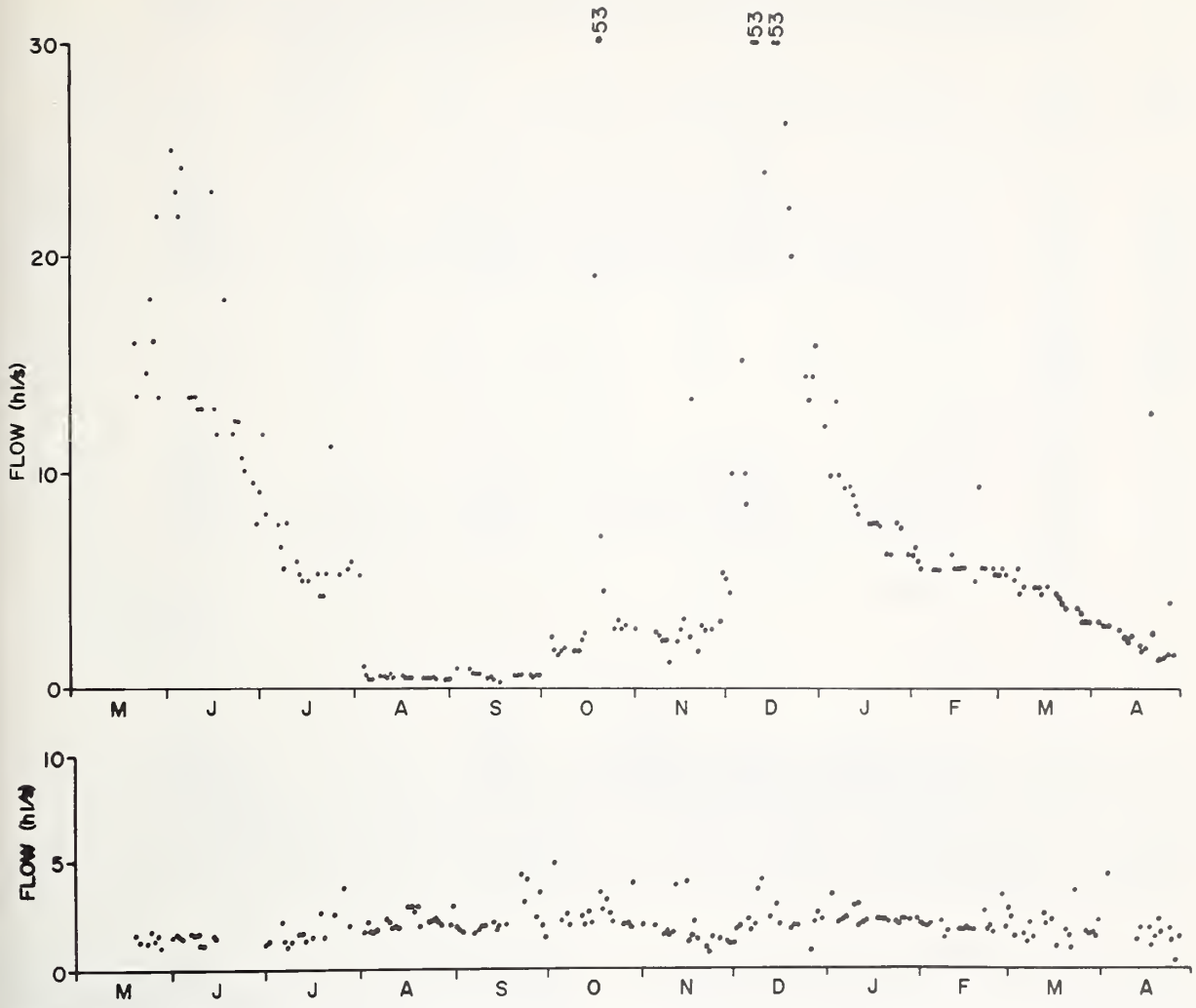

FIGURE 4.—Discharge flow of (*top*) Pennington Creek at station 2 and (*bottom*) Tishomingo National Fish Hatchery effluent, May 1971 through April 1972.

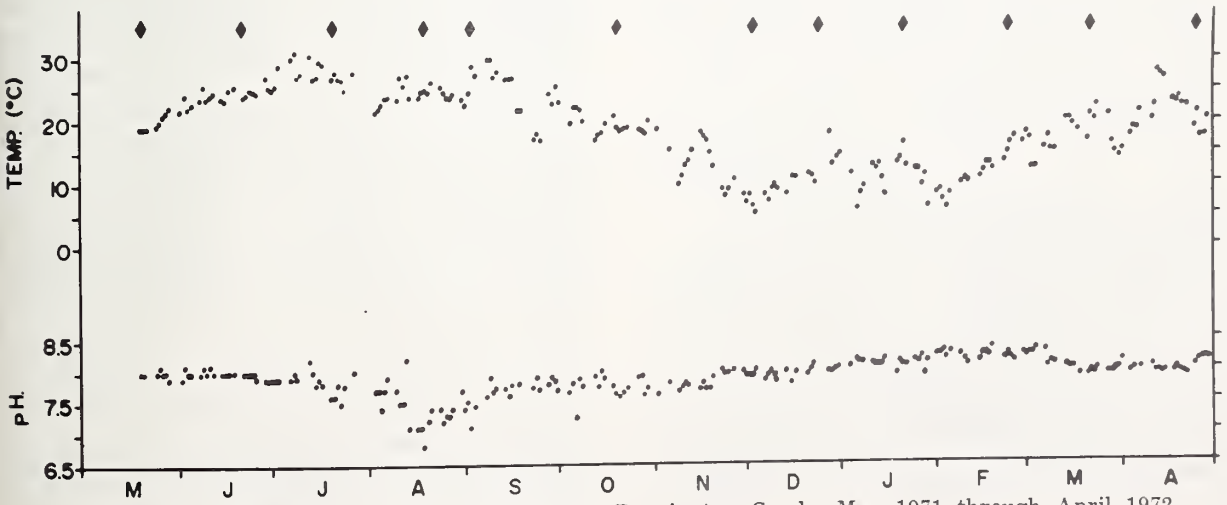

FIGURE 5.—Temperature and pH at station 2 on Pennington Creek, May 1971 through April 1972.

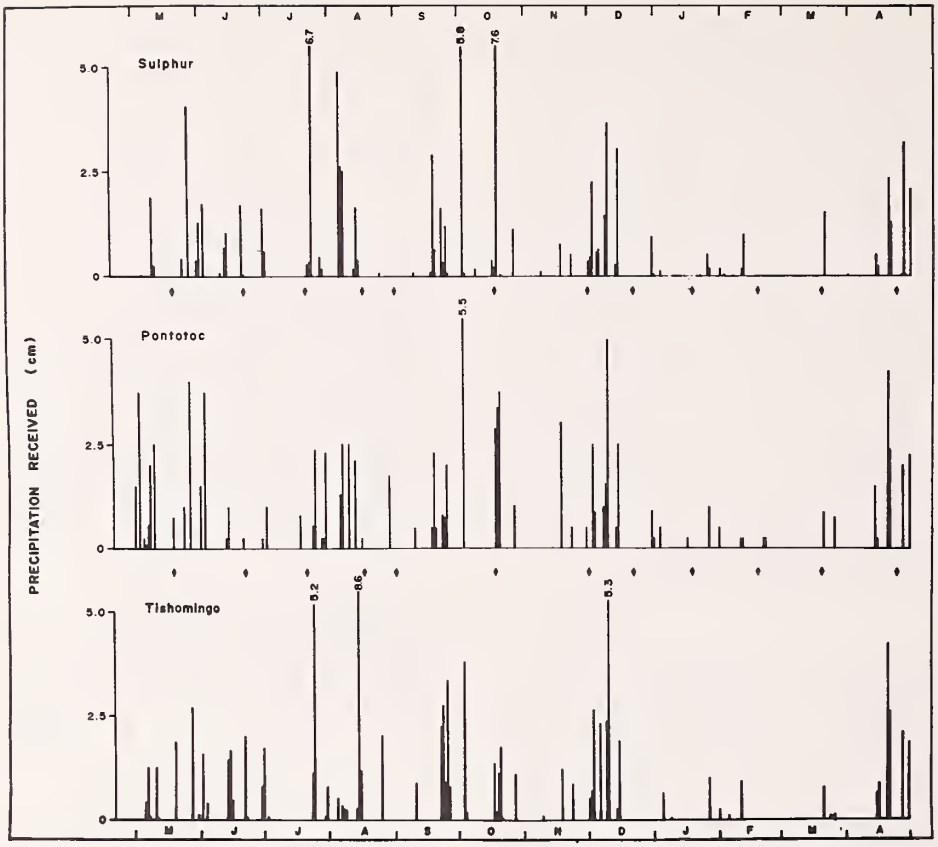

FIGURE 6.—Precipitation distribution for three Weather Service recording stations in the vicinity of the upper Pennington Creek watershed. The ◆ symbols indicate sampling dates.

from the drainage basin was 17.3 cm (6.8 in)/unit area annually, about 18% of the estimated precipitation.

Nutrient Content of Watershed Runoff

The quantities of P, N, Ca, and Mg discharged from the watershed through station 2 were calculated using concentration and flow data obtained in monthly samplings (table 1). The sampled mean flow differed only slightly from the measured annual mean flow for station 2 (fig. 4, top), so the calculated nutrient quantities are based on a representative flow estimate.

The discharge of total P from the watershed was nearly proportional to flow; thus, most of the P was discharged in the fall and spring months. The estimated total P discharged during the study period was about 0.18 kg/ha-m (0.048 lb/acre-ft) of runoff (all figures corrected for hatchery usage). On an areal basis the amount of P lost was about 30 g/ha (0.027 lb/acre). This level of phosphate transport is very low and compares with the results of Taylor et al. (*9*) of about 100 g of P lost/ha (0.09 lb/acre) annually for agricultural land in Ohio.

Approximately one-half of the total P was soluble orthophosphate. On two occasions the concentrations of soluble orthophosphate were anomalous. The first was in May 1971, when the soluble orthophosphate exceeded the total P determination. In May, the concentrations of soluble and total P were very low and quite similar, with the determined concentration of soluble orthophosphate exceeding the determined concentration of total P by a very small amount. The difference between the two concentrations was within experimental error. The flow-weighted nutrient loads reflect a multiplication factor required to convert concentration into nutrient load transported. The second anomalous result was found on December 22, 1971, when the soluble orthophosphate concentration was very low. This result may have been due to sampling post-

TABLE 1.—*Upper Pennington Creek watershed nutrient discharge at station 2*

Water sampling date	Flow (hl/s)	Phosphorus (kg/day)		Nitrogen (kg/day)				Ca^{+2} (kg/day)	Mg^{+2} (kg/day)
		Soluble ortho-phosphate	Total	NO_3^--N	NO_2^--N	NH_4^+-N	TKN		
1971									
May 19	16.0	2.75	2.21	11.6	<1.36	<1.4	24.8	7,590	6,620
June 22	12.3	1.17	2.76	31.9	.64	2.1	14.7	5,630	5,100
July 21	4.6	.35	1.42	4.3	<.05	<1.2	(1)	2,200	1,730
Aug. 23	.6	.05	.10	1.3	(2)	.1	1.0	250	170
Sept. 1	.6	.06	.08	1.0	.01	<.1	.2	250	190
Oct. 18	3.6	.09	.49	5.7	<.03	14.0	4.4	1,850	1,350
Dec. 1	5.1	.13	.39	15.4	.09	(2)	(2)	2,810	2,020
Dec. 22	20.1	.05	2.77	110.0	.17	4.3	42.3	10,750	8,320
1972									
Jan. 19	7.8	.34	.87	41.1	.20	2.7	16.4	3,900	2,820
Feb. 22	5.1	.13	.53	20.2	(2)	(2)	8.4	2,990	1,980
Mar. 20	4.6	.08	.55	10.8	.12	(2)	7.9	4,090	1,770
Apr. 24	1.4	.19	.20	4.7	.31	1.4	4.9	800	500
Mean	6.8	.45	1.03	21.5	<.25	<2.3	11.4	3,590	2,710

[1] No determination.
[2] Not detectable.

peak discharge containing low soluble orthophosphate concentrations.

Nitrate N and Kjeldahl N were discharged at rates of 2.7 and 1.9 kg/ha-m (0.74 and 0.52 lb/acre-ft) of runoff during the year, respectively. The nitrite N contributed from the watershed was less than 0.044 kg/ha-m (0.012 lb/acre-ft) of runoff annually. The total discharge of N in all forms was about 4.78 kg/ha-m (1.3 lb/acre-ft) of runoff annually or about 0.8 kg/ha (0.71 lb/acre).

Unpublished results from the Agricultural Research Service's Water Quality Management Laboratory in Durant, Okla., indicated that concentrations of about 1 mg/l total N and 16 micrograms per liter (μg/l) of total P would be found in the rainfall near this study site. Thus, each hectare would have received about 9.5 kg of N (8.5 lb/acre) and 0.16 kg of P (0.14 lb/acre) for the study period. The amounts of N and P discharged in the runoff were therefore less than the amounts estimated to have been received in rainfall.

The quantities of calcium and magnesium discharged in runoff were substantial but not unusual for study areas in this region. Concentrations of calcium and magnesium were rather constant, with slight indications of seasonal variation (table 2). Calcium and magnesium were discharged at the rates of 480 and 370 kg/ha-m (131 and 100 lb/acre-ft) of runoff during the year, respectively. The principal anion was bicarbonate. (See alkalinity values in table 3.)

Statistical Significance of Data

Station mean comparisons

Chemical and physical data from each station were statistically analyzed, and a summary of the analysis is presented in table 2. Highly or very highly significant differences were observed between station means for total Kjeldahl N, NO_3^--N, NO_2^--N, total P, soluble reactive P (orthophosphate), Ca, dissolved oxygen, alkalinity, suspended and settleable solids, BOD, and total coliform counts.

Total Kjeldahl N content represents the total ammonia N and organic N contained in the water samples. The total Kjeldahl N concentrations were relatively low. Application of Duncan's multiple-range test (table 3) shows that the Kjeldahl N concentrations at station 3, the hatchery effluent station, were measurably different from those at the other stations. The mean increase in concentrations at station 3 relative to stations 1, 2, and 6 was about 0.15 mg/l total

TABLE 2.—*Analysis of variance*[1] *summary for year-long survey of water-quality parameters*

Variable	Level of significance[2]	
	Between station means	Between sampling-date means
Nitrogen:		
Kjeldahl	**	**
NH_4^+	n.s.	**
NO_3^-	***	*
NO_2^-	***	**
Phosphorus:		
Total	**	*
Soluble orthophosphate	**	***
Calcium	**	**
Magnesium	n.s.	**
pH	n.s.	***
Temperature	n.s.	***
Dissolved oxygen	***	***
Alkalinity	***	***
Solids:		
Suspended	***	n.s.
Settleable	***	*
Total	n.s.	***
Biochemical oxygen demand (5-day)	***	n.s.
Coliform counts:		
Total	***	***
Fecal	n.s.	***

[1] Analysis of variance was conducted using Fisher's *F*-test (*8*).

[2] n.s.=not significant.
*=significant at 0.05 level=significant difference.
**=significant at 0.01 level=highly significant difference.
***=significant at 0.005 level=very highly significant difference.

Kjeldahl N. Since there was no significant difference among station means of ammonia content, the Kjeldahl N contributed by the hatchery to Pennington Creek was primarily organic in nature.

Very highly significant differences between station mean concentrations were observed with nitrate N and nitrite N. The nitrate concentration exiting the hatchery was measurably lower than that entering the hatchery ponds. There was a general decline in nitrate N with distance downstream (compare stations 1, 2, and 6), and the decline appeared to be accelerated within the hatchery. Nitrate N was the only nitrogen component which decreased in the hatchery effluent relative to the upstream locations.

Station 3, the effluent station, recorded nitrite concentrations almost twice as high as the three upstream locations. The increase in nitrite does not represent a large quantity of total N, but it does indicate, with the total Kjeldahl N concentrations, that a higher level of biotic activity is sustained in the hatchery ponds than in Pennington Creek. A particularly large increase in nitrite N, observed in April, was responsible for a nonsignificant difference observed between the mean of station 5 and those of stations 3 and 4.

Total P concentrations for stations 1, 2, and 6, the three upstream stations, consistently ranged between 15 and 30 μg/l. Statistical analysis of the data confirmed the casual observation that the effluent at station 3 had a measurably greater concentration of both total and soluble orthophosphate. When $\log_{10}$ concentrations were statistically analyzed, the downstream stations had significantly higher concentrations than stations 1, 2, or 6. Logarithmic transformations were used for the statistical analysis to obtain homogenous mean variances. Soluble orthophosphate accounted for about 20% of the total P exiting the hatchery and almost 40% of the P at the upstream stations.

During the last 3 months of the observation period, total water-soluble P concentrations were also determined for each site, including inorganic orthophospate, organic phosphate, and possibly some non-acid-labile phosphate which pass through a 0.45 μm Millipore filter (table 4). Quite often, about 50% of the total P was water-soluble P, and about one-half of this quantity was inorganic orthophosphate or acid-labile phosphate. Station 3 was an exception in that the total soluble P contents were 16%, 28%, and 11% of the total P content in February, March, and April, respectively.

It is important to note that while statistically significant increases in P, total Kjeldahl N, and nitrite N occurred in the hatchery effluent, the concentrations of these nutrients were relatively low and caused very slight increases in the downstream concentrations in Pennington Creek. Also, nitrate N, Ca, and alkalinity decreased in the hatchery effluent and at downstream stations relative to the three upstream stations.

The BOD, dissolved oxygen content, and suspended and settleable solids were measurably higher in the hatchery effluent than at the upstream stations. Increase in dissolved oxygen in

TABLE 3.—*Sampling-station means of water-quality measurements having significantly different means, monthly survey*[1]

Station	Nitrogen (mg/l)			Phosphorus[2]		Ca^{+2} (mg/l)
	TKN	NO_3^--N	NO_2^--N	Total	Soluble orthophosphate	
1	0.19a	0.50a	0.006bc	1.28c	0.70c	66a
2	.17a	.33bc	.004c	1.23c	.76bc	63ab
3	.35b	.28c	.010a	1.83a	1.05a	59c
4	.22a	.31bc	.008ab	1.53b	.94ab	59c
5	.21a	.30bc	.007abc	1.49b	1.07a	60bc
6	.21a	.35b	.006bc	1.22c	.69c	64ab

	Alkalinity (mg/l)	BOD (mg/l)	Dissolved oxygen (mg/l)	Solids[2]		Total coliform population[2]
				Suspended	Settleable	
1	320a	0.9b	7.9b	0.61c	0.47b	3.31b
2	310b	.9b	8.4ab	.45c	.40b	3.17b
3	300c	2.0a	8.7a	1.20a	1.29a	4.08a
4	300c	1.3b	8.2ab	1.02ab	1.07a	3.86ab
5	300c	.9b	8.4ab	.73bc	.53b	3.55ab
6	310b	1.1b	7.2c	.64c	.62b	3.90ab

[1] Values followed by the same letter are not significantly different.

[2] Numbers in these columns represent $\log_{10}$ transformations of the total phosphorus and orthophosphate concentrations in μg/l, suspended solids and settleable solids concentrations in mg/l, and total coliform populations recorded as individual organisms. Statistical analyses were conducted on the transformed data.

the hatchery effluent could have had two causes. The hatchery effluent canal is a relatively narrow channel, and a rather turbulent effluent flow occurred below the Parshall flumes. Turbulence exposes a greater quantity of water to the air and facilitates oxygen absorption and distribution within the discharge waters. All sampling sites where rapid or turbulent flow occurred recorded higher dissolved oxygen concentrations than the two sites where water was placid and slow moving.

A second process which could have contributed higher concentrations of dissolved oxygen in the effluent waters was discharge of water enriched in dissolved oxygen within the hatchery by mechanical agitation or algal production of oxygen. Evidence of algal oxygen production is clearly shown for August and September by the data on dissolved oxygen concentrations in table 8. The levels of Kjeldahl N, total P, suspended solids, and settleable solids could have been due, in part, to increases in plankton discharged from the hatchery or developed in the hatchery effluent canal. This possibility is important because the introduction of dissolved or nonliving suspended materials would increase the nutrient supply and the oxygen demand, whereas the discharge of plankton would not be expected to contribute to substantially increased nutrient levels in Pennington Creek (*2*), only to increased oxygen. Growth of plankton could increase stream productivity and simultaneously minimize the pollution potential of the hatchery nutrient discharge.

Total coliform counts were significantly greater in the hatchery effluent than in the water at stations 1 and 2, but not significantly greater than those at the downstream stations or at station 6. Thus, it is apparent that hatchery activity was not entirely responsible for the increase in total coliform numbers. If only the downstream stations had shown higher coliform counts, the activity of the hatchery could have been considered a prime factor in the elevated total coliform counts. Only total Kjeldahl N mean concentrations showed a statistical (and highly significant) correlation with total coliform counts. Thus, the presence of organic substrates may have been at least partially responsible for the differences observed among total coliform counts. The total coliform counts at station 6 may be related to the dense bottom-rooted

TABLE 4.—*Forms of water-soluble phosphorus in the last three monthly samples*

Station and phosphorus form	Phosphorus content (μg/l)		
	Feb.	Mar.	Apr.
Station 1:			
Orthophosphate	9	4	8
Nonorthophosphate	2	40	3
Total	11	44	11
Station 2:			
Orthophosphate	3	2	18
Nonorthophosphate	3	10	3
Total	6	12	21
Station 3:			
Orthophosphate	4	2	26
Nonorthophosphate	2	9	7
Total	6	11	33
Station 4:			
Orthophosphate	2	2	15
Nonorthophosphate	4	5	5
Total	6	7	20
Station 5:			
Orthophosphate	3	3	25
Nonorthophosphate	3	4	6
Total	6	7	31
Station 6:			
Orthophosphate	3	2	6
Nonorthophosphate	2	8	7
Total	5	10	13

vegetation in the supply canal which, through decay and nutrient cycling, promotes a higher level of activity. The relatively high coliform counts in hatchery effluent may have been a result of fertilization and addition of large quantities of fishfood to supply water with a relatively high initial coliform count.

Sampling-date mean comparisons

All variables had significantly different sampling-date means except suspended solids and BOD (table 2). Further statistical analyses were conducted using Duncan's multiple-range test and are summarized in table 5.

Total Kjeldahl N concentrations showed significantly different sampling-date means, but no well-defined seasonal trend was found. Ammonia N concentrations were generally less than 0.1 mg/l and varied erratically. Magnesium, pH, total solids, and settleable solids were similar to ammonia N and nitrite N in that statistically significant differences were found among different dates; however, no seasonal trends were found. Fluctuations of total solids may have been partially due to a combination of temperature and pH changes which affected the level of carbonate dissolved in the stream. Settleable-solids means did not show any annual pattern.

Seasonal variations were apparent in the sampling-date means for nitrate N, total P, soluble orthophosphate, Ca, alkalinity, dissolved oxygen, and temperature. The temperature and oxygen mean values followed their anticipated annual cycles. Minimum mean temperatures and maximum dissolved oxygen contents occurred in the winter, and maximum temperatures occurred in the summer with reduced oxygen concentrations.

Alkalinity mean concentrations also showed a well-defined seasonal trend with minimum concentrations in August and October and highest concentrations in December and February. Alkalinity measurements showed expected influences of both pH and temperature changes.

Nitrate N concentrations tended to increase in the winter and decrease in the late spring and early summer. The seasonal variation of nitrate N concentrations was not clear, but there was a definite trend similar to those of alkalinity and dissolved oxygen.

Total P and soluble orthophosphate mean concentrations tended to exhibit maximum concentrations during the summer and minimal concentrations during the winter. The seasonal variations can be attributed to hatchery activity which had a peak level during the late spring and the summer. In support of this conclusion, mean total and orthophosphate concentrations in the winter months were very similar to the station mean concentrations of the upstream sampling sites which did not show seasonal variation (data not shown).

P concentrations at downstream sites were three to four times greater from April through November than in the rest of the year, which indicates that much of the P contributed by the hatchery was not being retained by the sediment

TABLE 5.—*Sampling-date means of water-quality measurements having significantly different means, monthly survey*[1]

Water sampling date	Nitrogen (mg/l)				Phosphorus[2]		Ca^{+2} (mg/l)	Mg^{+2} (mg/l)
	TKN	NO_3^--N	NH_4^+-N	NO_2^--N	Total	Ortho-phosphate		
1971								
May 19	0.23b	0.11g	0.000d	([3])	1.63a	1.56a	53e	48a
June 22	.15bc	.23ef	.028cd	0.007bc	1.57bcd	1.11cd	51e	48a
July 21	([3])	.16fg	.068bc	.003cd	1.60abc	1.10cd	52e	45b
Aug. 17	.43a	.30de	.035cd	.007bc	1.55cd	1.06d	55e	38e
Sept. 1	.17bc	.41bc	.043bcd	.009b	1.58abcd	1.23b	56de	45b
Oct. 18	.23b	.24ef	.286a	.004cd	1.53d	.90e	52e	41cd
Dec. 1	.12c	.23d	.000d	.003cd	.83g	.68f	61bcd	45b
Dec. 22	.18bc	.61a	.004d	.001d	1.30e	([3])	63b	45b
1972								
Jan. 19	.11c	.59a	.026cd	.004cd	1.15f	.66f	57cde	42c
Feb. 22	.23b	.43b	.000d	.005bcd	1.18f	.56g	65b	45b
Mar. 20	.18bc	.29de	.004d	.004cd	1.61ab	.38h	115a	46b
Apr. 24	.42a	.35cd	.101b	.073a	1.35e	1.16bc	62bc	40d

Water sampling date	Dissolved oxygen (mg/l)	Alkalinity (mg/l)	pH	Temperature (° C)	Total solids (mg/l)	Settleable solids[2]	Coliform populations[2]	
							Total	Fecal
1971								
May 19	6.9defg	310cd	8.1a	19.5d	420a	([3])	3.70ab	1.36d
June 22	6.3g	320bc	8.0a	24.7b	330bc	0.84ab	4.07a	2.21abcd
July 21	6.2g	310de	([3])	([3])	320bc	—.02d	4.29a	2.55ab
Aug. 17	6.4fg	270f	7.4b	26.4a	300c	.90ab	4.13a	2.24abc
Sept. 1	7.2de	([3])	([3])	([3])	([3])	([3])	([3])	([3])
Oct. 18	6.8efg	270f	7.8a	20.4c	300bc	.50bc	4.38a	2.98a
Dec. 1	13.2a	320bc	7.9a	8.4h	360bc	1.17a	3.35bc	2.00bcd
Dec. 22	11.8a	330b	8.0a	10.9g	350bc	.58bc	([3])	([3])
1972								
Jan. 19	9.2b	330b	8.1a	13.6f	360bc	.08cd	2.88c	1.55cd
Feb. 22	7.7d	350a	8.2a	13.8f	350bc	1.12a	3.32bc	1.79bcd
Mar. 20	8.8c	310cd	7.8a	16.5e	320bc	1.24a	3.04c	1.74bcd
Apr. 24	7.1def	300e	8.0a	18.8d	370b	.88ab	3.72ab	2.39abc

[1] Values followed by the same letter are not significantly different.

[2] Numbers in these columns represent $\log_{10}$ transformations of the total phosphorus and orthophosphate concentrations in μg/l, settleable solids concentrations in mg/l, and total coliform and fecal coliform populations recorded as individual organisms. Statistical analyses were conducted on the transformed data.

[3] No determination.

and indigenous biota. There was virtually no change in soluble orthophosphate concentrations at the downstream locations relative to station 3, and only a slight decrease in total P concentrations was observed. Some decreases in P concentrations were expected due to sedimentation of particulate or nonsoluble P or dilution of the total flow with water containing little particulate P.

Both total and fecal coliform counts showed significantly different sampling-date means, both following a seasonal trend with maximum counts from June through September. In contrast to the sampling station means, however, neither total nor fecal coliform counts showed any correlation with any of the remaining variables or with net organic N (net organic N= total Kjeldahl N minus ammonia N).

Results of 24-Hour Survey

Pennington Creek flow diminished to its minimum level in August and September, and at this time the hatchery utilized a major portion of the total flow, about 75%. A 24-hour survey of wa-

ter-quality characteristics began at 10 p.m., August 31. Samples were withdrawn from each sampling site at 2-hour intervals and analyzed for four forms of nitrogen and suspended and settleable solids. In addition, the pH, temperature, dissolved oxygen content, and biochemical oxygen demand characteristics were measured. A summary of the statistical analysis of variance of the parameters measured is shown in table 6.

Station mean comparisons

Table 7 gives the results of Duncan's multiple-range test comparisons for those parameters with significantly different station means. No measurable differences were observed among stations for pH or suspended solids. Total Kjeldahl N concentrations were measurably greater at the hatchery discharge and downstream sites. An increase measured at the downstream sites was undoubtedly enhanced by the relative flow volumes. The total Kjeldahl N mean concentration recorded at station 4, however, was not proportional to the estimated flow volumes.

TABLE 6.—*Analysis of variance[1] summary for 24-hour survey of water-quality parameters*

Variable	Level of significance[2]	
	Between station means	Between sampling time means
Nitrogen:		
Kjeldahl	***	n.s.
NH_4^+	*	n.s.
NO_3^-	***	n.s.
NO_2^-	***	n.s.
pH	n.s.	***
Temperature	***	***
Dissolved oxygen	*	**
Solids:		
Suspended	n.s.	***
Settleable	***	n.s.
Biochemical oxygen demand (5-day)	***	n.s.

[1] Analysis of variance was conducted using Fisher's *F*-test (*8*).

[2] n.s. = not significant.
* = significant at 0.05 level = significant difference.
** = significant at 0.01 level = highly significant difference.
*** = significant at 0.005 level = very highly significant difference.

TABLE 7.—*Sampling-station means of water-quality measurements having significantly different means, 24-hour survey*[1]

Station	Nitrogen (mg/l)			
	TKN	NH_4^+-N	NO_3^--N	NO_2^--N
1	0.083c	0.028bc	0.670a	0.005bc
2	.052c	.010c	.220e	.002c
3	.410a	.086a	.360c	.016a
4	.200b	.061ab	.360c	.015a
5	.170b	.032bc	.290d	.008b
6	.110c	.043abc	.560b	.005bc

	Temperature (° C)	Dissolved oxygen (mg/l)	Settleable solids[2]	BOD (mg/l)
1	24.6c	7.2ab	0.93d	1.0c
2	24.0c	8.5a	1.25cd	.9c
3	26.2a	7.1ab	2.47a	3.1a
4	26.0ab	6.5b	2.05ab	1.9b
5	25.7ab	7.1ab	1.60bc	1.0c
6	25.5ab	6.2b	1.73b	1.1c

[1] Values followed by the same letter are not significantly different.

[2] Numbers in this column represent $\log_{10}$ transformations of the settleable solids concentrations in mg/l. Statistical analyses were conducted on the transformed data.

Since other parameters (NO_2^--N, NO_3^--N, NH_3-N, and temperature) indicated by their relative proportions that the flow measurements were accurately determined, some utilization or elimination of the total Kjeldahl N must have occurred before site 4 was reached.

Ammonia N and nitrite N concentrations were also higher in the hatchery effluent than in the upstream supply waters. The increase in ammonia N was not as clearly established as with nitrite N, but a trend was observed. The significant difference in the station mean ammonia N concentrations was in contrast to the year-long survey which indicated that the increase was nonpersistent. Mean concentrations of nitrite N were quite low, but did show about a threefold increase in the hatchery effluent and at the immediate downstream sampling site. Nitrite N usually constituted <0.1 % of the total N content of all samples analyzed.

The transformation of nitrate N in the hatchery was not as clearly defined as in the year-long survey, but a comparison of station 6 with station 3 indicates that as much as 40 % of the incoming nitrate N may have been converted to

some other form. The decrease in nitrate N was on the same order as the increase in the total Kjeldahl N. The net result was, then, a change in nitrogen form with no change in total quantity.

A measurable water-temperature increase occurred in the supply-canal water and was maintained at the hatchery and downstream sampling sites. The temperature increase may have been a result of flow velocity or canal geometry. There did not appear to be any significant influence of the hatchery activity on water temperature, although the effluent station did register the highest mean temperature. The short-term observation established that measurable differences existed, something which the less intensive, year-long study did not expose.

The BOD in the hatchery effluent was measurably greater than that measured at the upstream locations. The increase in BOD was not observed 8 km (5 mi) downstream from the effluent canal-creek junction. Differences between station mean dissolved-oxygen concentrations were not correlated with hatchery activities, even though analysis of variance and Duncan's multiple-range test did indicate measurable differences.

The mean concentrations of settleable solids were measurably higher at the effluent station and the immediate downstream site. The trend for these was similar to the trends of BOD, ammonia N, and total Kjeldahl N.

Sampling-time mean comparisons

Table 6 shows measurable sampling-time mean differences for pH, temperature, dissolved oxygen, and suspended solids, and table 8 shows comparisons of the sampling-time means for these four variables using Duncan's multiple-range test. No well-defined trend was observed for the pH measurements.

The mean temperature measurements followed a diurnal cycle with a minimum of 23.5° C at 8 a.m. and a maximum of 27.5° C at 4 p.m. Mean dissolved-oxygen content also exhibited distinct diurnal variation, but did not vary inversely with temperature as might be expected. This relationship could have occurred only if a substantial algal population had been present at all of the stations. (Recall that no well-defined trend was exhibited for station-mean dissolved-oxygen contents.) Oxygen production would have risen with increasing light intensity (It reached a peak of 9.2 mg/l at 4 p.m.), while oxygen consumption would have been continuous, depleting oxygen during the hours of darkness. Dissolved-oxygen content would have been expected to reach a minimum just at or prior to dawn, and the minimum did occur at about 6 a.m., with a 5.8 mg/l concentration of dissolved oxygen.

Mean concentrations of suspended solids also displayed a diurnal cycle which, while not as distinct, followed the same trend as the oxygen and temperature measurements. No good explan-

TABLE 8.—*Sampling-time means of water-quality measurements having significantly different means, 24-hour survey*[1]

Time	pH	Temperature (°C)	Dissolved oxygen (mg/l)	Suspended solids[2]
10 p.m.	7.7ab	25.4cd	7.0abcd	1.49ab
12 p.m.	7.6bc	25.3cd	6.5cd	1.26bc
2 a.m.	7.6bc	24.5def	6.6cd	1.49ab
4 a.m.	7.7ab	23.8ef	6.3cd	1.31abc
6 a.m.	7.7ab	23.6f	5.8d	1.80a
8 a.m.	7.5c	23.5f	5.9cd	1.74ab
10 a.m.	7.6bc	24.9cde	6.4cd	1.73ab
12 a.m.	7.6bc	25.6cd	7.5abcd	1.15bc
2 p.m.	7.8a	27.1ab	8.9ab	1.24bc
4 p.m.	7.7ab	27.5a	9.2a	1.17bc
6 p.m.	7.7ab	26.8ab	8.1abc	.91c
8 p.m.	7.7ab	26.0bc	6.9bcd	1.20bc

[1] Values followed by the same letter are not significantly different.

[2] Numbers in this column represent $\log_{10}$ transformations of the suspended solids concentrations in mg/l. Statistical analyses were conducted on the transformed data.

ation for this trend is found in comparing other parameters. This appears to be a general characteristic which was not confined to an individual sampling site.

The Hatchery Nutrient Budget

To further investigate the pollution potential of the hatchery, a statement of nutrient input and output was developed. Nutrient input to the hatchery waters came from watershed nutrient discharge contained in runoff, commercial fishfood and fertilizer incorporated at the hatchery, and rainfall. All output was channeled through the effluent canals and monitored at station 3.

Nutrient input to hatchery

A factor influencing the nutrient budget calculations was the fact that approximately 65 ha (160 acres) surrounding the hatchery and the small community of Reagan, Okla., also discharged a portion of their surface runoff through the hatchery effluent canal. Records indicate that on three occasions some precipitation occurred in the associated drainage area shortly before sampling. It appears that the observed flow (table 9) was not influenced substantially by runoff from the immediate drainage area in May or June. Some contribution from the associated drainage area may have been responsible, however, for the moderately increased flow rate and nutrient concentration in October and may have caused a slight overestimate (<10%) of hatchery discharge.

Two flow measurements were recorded in May. The first was recorded immediately prior to drainage of several of the rearing ponds and the second during pond drainage which continued for 1 or 2 days. The nutrient observations recorded in May were the only ones obtained on effluent that included pond drainage water. Since the ponds are drained for less than 1 month in each year, a slight overestimate of the discharge from the hatchery could be made in calculating the nutrient budget if observations made during drainage were considered normal. However, the flow average was obtained using the value of 1.4 hl/s (5 ft^3/s) for May. The use of the lower flow value for May tends to compensate for any error introduced by use of the nutri-

TABLE 9.—*Tishomingo National Fish Hatchery nutrient discharge at station 3*

Water sampling date	Flow[1] (hl/s)	Phosphorus (kg/day)		Nitrogen (kg/day)				Ca^{+2} (kg/day)	Mg^{+2} (kg/day)
		Soluble ortho-phosphate	Total	NO_3^--N	NO_2^--N	NH_4^+-N	TKN		
1971									
May 19[2]	(1.4)	([3])	([3])	([3])	([3])	([3])	([3])	([3])	([3])
May 19[4]	(2.8)	1.47	3.28	0.7	0.12	([3])	4.3	610	610
June 22	(1.7)	.35	.98	2.1	.19	0.6	2.8	730	700
July 21	(2.6)	.34	1.73	2.8	.22	2.9	([3])	1,080	990
Aug. 23	2.2	.23	3.51	4.2	.15	1.1	14.7	960	750
Sept. 1	2.0	.29	1.70	6.0	.27	1.5	7.0	([3])	([3])
Oct. 18	3.6	1.63	3.49	5.7	.52	12.7	11.3	1,480	1,300
Dec. 1	1.2	.06	.23	2.6	.04	([5])	2.3	610	460
Dec. 22	2.0	.01	.47	8.4	.13	([5])	3.5	1,110	730
1972									
Jan. 19	2.3	.12	.36	11.4	.10	.2	1.2	1,140	850
Feb. 22	2.7	.10	.89	8.7	([5])	([5])	9.1	1,450	1,050
Mar. 20	1.8	.03	.60	4.6	.06	1.2	2.2	1,790	690
Apr. 24	1.9	.42	4.87	4.5	.45	1.9	10.2	900	630
Mean	2.1	.42	1.84	5.14	.19	1.84	6.23	1,080	800

[1] Values in parentheses are estimated values.
[2] Flow value was recorded prior to pond drainage.
[3] No determination.
[4] Flow value was recorded during pond drainage.
[5] Not detectable.

ent concentrations observed in the pond-drainage effluent.

The total quantity of feed distributed in the ponds during the observation period was about 48,000 kg (105,000 lb). The daily quantities distributed are shown in figure 7. Maximum feeding rates of greater than 410 kg (900 lb)/day occurred during late summer and early autumn. Table 10 shows the amounts of N, P, Ca, and Mg contained in the fishfood used at the hatchery (identified as feed No. 1) and compares them with those of two other common brand names.

The total Kjeldahl N contributed to the hatchery waters from the feed was about 2,400 kg (5,300 lb). The contributions of ammonia N, nitrite N, and nitrate N were relatively small, amounting to about 22.6, 0.5, and 38.5 kg (50, 1, and 82 lb), respectively.

Almost all of the P content of the feed appeared to be readily acid soluble. This suggests that the P contained in the fishfood was almost entirely inorganic and was probably derived from calcium phosphate in the added bonemeal. The quantities of P and water-soluble P added to the hatchery waters were about 825 and 118 kg (1,820 and 262 lb), respectively.

Nutrient determinations indicated that about 1,130 kg (2,500 lb) of calcium and about 124 kg (273 lb) of magnesium were being added to the hatchery waters in the fishfood. A large portion of the calcium contributed from the fishfood was probably contained in the bonemeal additive. The quantities of calcium and magnesium added to the hatchery waters through fishfood were insignificant (<0.1%) relative to the total quantities initially present in Pennington Creek.

Commercial-fertilizer applications constituted the third-largest input of nutrients into the hatchery ponds. Commercial fertilizers such as ammonium nitrate (33% N) and concentrated superphosphate (46% P_2O_5) were added in April and May of both 1971 and 1972 to increase the plankton population, which serves as an auxiliary fishfood supply within the ponds. Meat scraps were also used as a fertilizer (5.1% P and 8.2% N) in the spring months.

In 1971, 100 kg (215 lb) of ammonium nitrate, 920 kg (2,030 lb) of concentrated superphosphate, and 1,090 kg (2,400 lb) of organic fertilizer were added to the hatchery ponds. The fertilizer contained 124 kg (270 lb) of N and 245 kg (540 lb) of P.

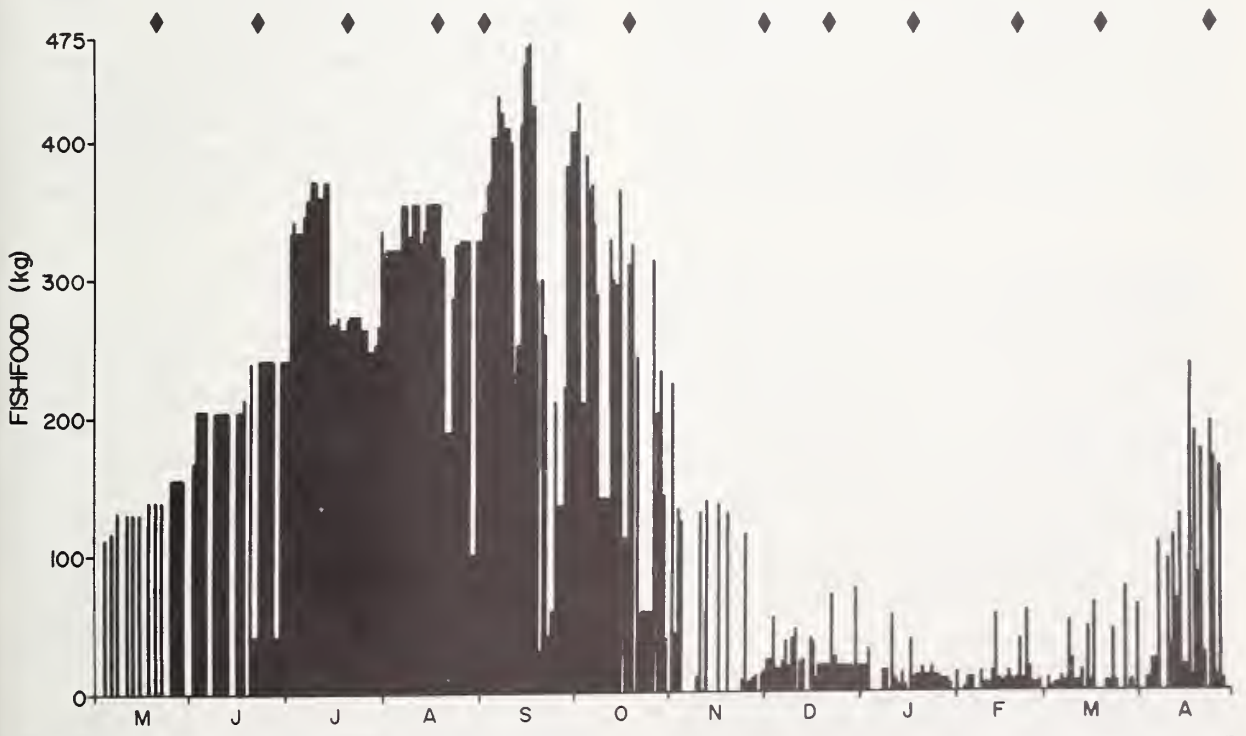

FIGURE 7.—Quantity and distribution of fishfood added to the Tishomingo National Fish Hatchery ponds, May 1971 through April 1972. The ◆ symbols indicate sampling dates.

TABLE 10.—*Nutrient content of commercial fishfoods*
[Percent]

Fishfood brand	Nitrogen				Phosphorus			Ca^{+2}	Mg^{+2}
	TKN	NO_3^--N	NO_2^--N	NH_4^+-N	Total	Acid-soluble	Water-soluble		
1	5.08	0.079	0.00105	0.048	1.73	1.79	0.25	2.38	0.26
2	5.75	.056	.00135	.042	1.06	.87	.34	1.25	.30
3	5.55	.103	.00068	.036	2.03	1.80	.23	2.82	.33

The fertilizer additions in April 1972 were 325 kg (720 lb) of ammonium nitrate on April 24, and 260 kg (575 lb) of concentrated superphosphate and 230 kg (500 lb) of organic fertilizer on April 17. This fertilizer contained about 128 kg (280 lb) of N and about 64 kg (140 lb) of P.

The addition of fertilizer in 1971 did not appear to influence the results of the chemical analyses conducted on the hatchery effluent (table 9). In 1972, however, the April analysis of hatchery effluent showed quite high levels of total P. No evidence of nitrogen enhancement was observed in 1971, partially because water samples were removed at station 3 just prior to or simultaneously with the addition of ammonium nitrate to the pond water. Another factor which influenced the rate of fertilizer-nutrient transport from the ponds was the practice of using supply water to maintain the water levels of the hatchery ponds; i.e., continuous flowthrough ponds were not used at the hatchery during rearing operations, and pond drainage was used primarily to facilitate harvest and transfer operations.

Evaporation and precipitation also influenced the concentrations in the hatchery waters. Rainfall contributed an estimated 140 kg (300 lb) of N and 2.2 kg (5 lb) of P during the study period. No measure of flow into the hatchery supply canal was made so the only estimate of nutrients obtained from the watershed was made from the effluent flow. The effluent flow must be corrected, however, for evaporative losses.[4] Evaporation of water concentrates the nutrients. When an increase in nutrient concentration is recorded, the hatchery activities are credited with an apparent nutrient addition, since all elevated concentrations at station 3 were initially regarded as the direct result of hatchery input. The concentrating effect of evaporation caused the hatchery activities to be credited with an apparent addition of 140 kg (300 lb) of N and 20 kg (50 lb) of P. Therefore, a correction was entered in the hatchery budget (table 11).

The largest single contribution of N to the hatchery effluent came from the upper Pennington Creek watershed. The quantities of the various N forms and P originally present in the hatchery supply waters can be estimated from the data in table 1, since the hatchery water was a portion of the watershed runoff monitored at station 2. The estimated quantities of N and P contributed to the hatchery waters from watershed runoff were as follows: total Kjeldahl N, 1,450 kg (3,200 lb); nitrite N, 30 kg (65 lb); nitrate N, 2,450 kg (5,405 lb); ammonia N, 400 kg (995 lb); total P, 120 kg (265 lb); and soluble P, 50 kg (110 lb).

Nutrient output from hatchery

Estimates of the nutrient loads exiting the hatchery were obtained by combining the hatchery-effluent flow volumes with their respective nutrient concentrations (table 11). By comparing the nutrient load entering the hatchery from Pennington Creek with the nutrient loads exiting the hatchery, an estimate of the contribution of the hatchery activity to the nutrient status of Pennington Creek could be obtained. Table 11 shows a comparison of the initial or anticipated nutrient loads (those which would exist without hatchery activity) with the determined nutrient loads in the hatchery effluent. Also included in table 11 is a summary of the nutrients added to the hatchery waters as feed or fertilizers.

[4] Mean annual lake evaporation at the Tishomingo National Fish Hatchery is approximately 135 cm (54 in). The evaporative loss from 15.3 ha (37.5 acres) of surface is about 21 hm (170 acre-ft)/yr, or about 3.43% of the total hatchery discharge (*10*).

TABLE 11.—*Nutrient load contributed to Pennington Creek during study year from the Tishomingo National Fish Hatchery*

[Kilograms]

Nutrient form	Nutrient load			Added as—	
	In supply load	In hatchery effluents	Apparent hatchery contribution	Fishfood	Fertilizer
Nitrogen:					
Nitrate	2,450	1,870	−580	49	71
Nitrite	30	70	40	1	...
Ammonia[1]	400	650	250	23	71
Total Kjeldahl	1,450	2,270	820	2,410	...
Concentration[2]	140	.....	−140	.....	...
Rainfall	140	.....	−140	.....	...
Other	.....	.....	.....	.....	110
Total	4,210	4,210	0	2,460	252
Phosphorus:					
Total P	120	620	500	825	309
Soluble orthophosphate[3]	50	150	100	71	...
Concentration[2]	20	.....	−20	.....	...
Rainfall	2	.....	−2	.....	...
Total	142	620	478	825	309

[1] Values included in total Kjeldahl N.

[2] Concentration due to evaporation.

[3] Values included in total P.

The effect of the hatchery operation appeared to have been a reduction of the nitrate N load by about 580 kg (1,280 lb) and an increase in total Kjeldahl N and nitrite N loads by 820 kg (1,810 lb) and 40 kg (100 lb), respectively. Ammonia N accounted for approximately 250 kg (550 lb) of the total Kjeldahl N fraction discharged in the hatchery effluent. While a significant change in the proportions of the various N forms was evident in the hatchery effluent, the net effect of the hatchery activity on the total N load exiting the hatchery was nil. Thus, it is estimated that 2,810 kg (6,200 lb) of N was either incorporated into the fish crop, volatilized as gaseous N, or went undetected as seepage loss. A few potential factors such as deposition of dust-borne N, N fixation or volatilization by indigenous biota, and seepage losses were not evaluated in the estimate of the nutrient budget.

The P budget for the hatchery operation was markedly different from that of N. The total quantity of P discharged from the hatchery was about 620 kg (1,370 lb). The increase of the P content of the hatchery waters of 480 kg (1,060 lb) over the P load in the supply waters represents about 42% of the total P added to the hatchery water as feed and fertilizer (table 11). The data in tables 3 and 9 suggest that the net contribution of P to Pennington Creek by the hatchery was predominantly particulate in form. Further investigation of P utilization by fish when supplied as bonemeal additive, P_2O_5, or as phosphate and the forms exiting such feeding operations may be required before the importance of various P forms can be determined.

The accuracy of streamflow and nutrient-content loads was also briefly examined. By combining flow volumes at stations 2 and 3 (tables 1 and 9) to estimate the flow at station 4, and by using the determined nutrient concentrations at station 4, estimates of the nutrient loads passing this station were made. The determined nutrient loads passing station 4 were then compared with the combined nutrient loads at station 2 and 3. Since several nutrients had significantly different concentrations at stations 2 and 3, the relative flow-volume measurements would have to have been accurate if estimated and determined nutrient loads at station 4 agreed. The comparison of nutrient loads in table 12 indicates that the relative flow rates were accurately determined.

TABLE 12.—*Year-long flow-weighted nutrient budget for three sampling stations*

Nutrient	Station 2	Station 3	Station 4 Determined	Station 4 Estimated[1]
Nitrate N ..... kg	7,850	1,870	9,260	9,720
Nitrite N ..... kg	100	75	135	175
Ammonia N ..... kg	890	650	1,210	1,540
TKN ..... kg	4,130	2,270	5,080	6,400
Total phosphorus ..... kg	375	620	1,230	995
Orthophosphate phosphorus ..... kg	175	145	490	320
Calcium ..... 1,000 kg	1,430	390	1,770	1,820
Magnesium ..... 1,000 kg	1,040	290	1,360	1,330

[1] Represents the sum of stations 2 and 3.

SUMMARY AND CONCLUSIONS

During the study period (April 1971 through May 1972) the upper Pennington Creek watershed received an estimated 98.6 cm (38.8 in) of rainfall and discharged 17.5 cm (6.9 in) of runoff per unit of area. Chemical analyses of rainfall from a separate study site in the region indicated that the rainfall had contributed 9.5 kg/ha (8.5 lb/acre) of N and 0.16 kg/ha (0.14 lb/acre) of P during the study year. Chemical analysis of the watershed discharge waters indicated that about 4.78 kg/ha-m (1.3 lb/acre-ft) of N, and 0.18 kg/ha-m (0.048 lb/acre-ft) of P were removed from the watershed in the surface runoff. Considered by themselves these results show that the watershed was a net accumulator of both N and P received in the precipitation. The approximate mean nutrient concentrations discharged from the watershed were total Kjeldahl N, 180 μg/l; NO_3^--N, 410 μg/l; NO_2^--N, 5 μg/l; NH_4^+-N, 50 μg/l; total P, 19 μg/l; and soluble orthophosphate P, 8 μg/l.

A total quantity of 48,000 kg (105,000 lb) of feed was added to the hatchery waters during the study period. Analysis showed that the feed fed contained 2,410 kg (5,300 lb) of TKN, 50 kg (108 lb) of NO_3^--N, 0.5 kg (1 lb) of NO_2^--N, 830 kg (1,820 lb) of total P, and 70 kg (157 lb) of soluble orthophosphate P. An additional 252 kg (550 lb) of N and 309 kg (680 lb) of P were added as fertilizer in the spring to promote plankton growth.

The statistical evaluations of monthly physical and chemical measurements made on water entering, exiting, and bypassing the hatchery showed that the hatchery activity decreased the nitrate N, Ca, and total alkalinity concentrations and increased the concentrations of total Kjeldahl N, nitrite N, total N, soluble P, dissolved oxygen, BOD, suspended solids, and settleable solids. The approximate mean annual hatchery-discharge concentrations of the variables studied were total Kjeldahl N, 350 μg/l; NO_3^--N, 280 μg/l; NO_2^--N, 10 μg/l; NH_3-N, 60 μg/l; total P, 100 μg/l; soluble orthophosphate P, 24 μg/l; Ca, 59 mg/l; Mg, 44 mg/l; dissolved oxygen, 8.7 mg/l; BOD, 2 mg/l; suspended solids, 23 mg/l; settleable solids, 30 mg/l; and total solids, 342 mg/l. Seasonal concentration variations were observed for nitrate N, total P, soluble orthophosphate P, Ca, and total alkalinity. Seasonal variations in P concentrations appeared to be due solely to hatchery operations.

Statistical evaluations of total and fecal coliform counts showed that higher mean total coliform counts existed in the hatchery effluent but that no differences could be found between sampling-station mean fecal coliform bacteria counts. When sampling-station means were compared, a significant correlation between total Kjeldahl-N and total coliform counts appeared. Statistical evaluation of the total and fecal coliform counts for different sampling dates showed that both bacterial populations declined during the winter season. A significant correlation between the previous sampling-date temperature

and total or fecal coliform counts was indicated; however, no other variables measured had any correlation with coliform counts.

A 24-hour survey of N, dissolved oxygen, BOD, and solids concentrations supported conclusions drawn from the annual survey. The 24-hour survey also indicated that measurable increases in the ammonia N concentrations could be detected in the hatchery effluent waters. All stations monitored during the 24-hour survey showed changes in dissolved oxygen concentrations which varied directly with water temperature. The paradoxical variation in dissolved oxygen content was presumed to be due to active algal populations.

Calculations of N balances for the hatchery showed that measurable changes occurred in the various forms of N, but that no significant changes occurred in the total quantity of N contained in the waters. Pronounced increases in the total quantity of P contained in the discharge from the hatchery were observed. Analysis of the fishfood added to the water indicated that most of the increase in P was from P added as bonemeal. Analysis of the effluent water indicated that a substantial portion of the P discharged was in particulate form, perhaps as plankton.

Examination of the data shows that for most of the parameters monitored in this study the fish hatchery operation has little effect on water quality. Further support for this conclusion was obtained in a 1971 survey of pollution-sensitive organisms such as damsel flies, mayflies, beetles, Diptera, snails, and clams which showed increased populations below the hatchery effluent.[5] Although the hatchery discharged water having measurably greater concentrations of total Kjeldahl N and a greater BOD, no depression of the dissolved oxygen content was observed. The shallowness and turbulence within Pennington Creek and the effluent canals were probably responsible for maintaining a relatively high oxygen concentration within the stream and hatchery discharge canals.

[5] Peters, D. N. 1973. Personal postal communication with the authors. Address: U.S. Environmental Protection Agency, Region VI, 1600 Patterson, Suite 1100, Dallas, Tex. 75201.

Among the nutrients studied, only P appears to be discharged in quantities greater than those initially present in that portion of the watershed runoff used within the hatchery. Concentrations of total and soluble orthophosphate P below the hatchery effluent were relatively low. However, the persistence of greater P concentrations there than above the hatchery suggests that more intensive utilization of these waters for fish culture could possibly further increase P concentrations in Pennington Creek.

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